U.S. Department
of Transportation
**Federal Aviation
Administration**

Advisory Circular

Subject: PRESSURIZATION, VENTILATION AND OXYGEN SYSTEMS ASSESSMENT FOR SUBSONIC FLIGHT INCLUDING HIGH ALTITUDE OPERATION

Date: 9/10/96
Initiated by: ANM-110
AC No: 25-20
Change:

1. PURPOSE. This advisory circular (AC) sets forth guidance on methods of compliance with the requirements of part 25 of the Federal Aviation Regulations (FAR) pertaining to pressurization, ventilation, and oxygen systems, especially as they pertain to high altitude subsonic flight. As with all AC material, it is not mandatory and does not constitute a regulation. The applicant may elect to follow alternate methods provided that these methods are also found by the FAA to be an acceptable means of complying with the requirements of part 25. Because the guidance on the methods of compliance presented in this AC are not mandatory, the terms "shall" and "must," when used herein, apply only to an applicant that chooses to follow a particular method without deviation.

2. RELATED FAR SECTIONS. This AC specifically addresses various sections of the FAR: pressurized compartment loads (§ 25.365(d)), ventilation (§ 25.831), pressurized cabins (§ 25.841) and equipment standards for oxygen dispensing units (§ 25.1447), that were introduced at Amendment 25-87. Sections 25.571 at Amendment 25-45 and 25.775 at Amendment 25-38 are also pertinent to this AC. Although beyond the scope of this AC, other related parts of the FAR (e.g., parts 91, 121, and 135) contain requirements pertaining to high altitude flight that must be considered.

3. BACKGROUND. Part 25 was recently amended to include standards for high altitude operation of subsonic transport category airplanes. The adopted standards differ somewhat from those previously contained in special conditions and from previously established part 25 systems and structural integrity requirements. The standards were written to address physiological limitations at high altitudes and changes in equipment technology. The standards adopted as Amendment 25-87 pertain to operation of subsonic airplanes to a maximum altitude of 51,000 feet, although many of the requirements addressed therein relate to operations at lower altitudes (below 41,000 feet) as well. It is envisioned that additional standards would have to be issued in the form of special conditions for flight above 51,000 feet, for high altitude operation of supersonic airplanes, and for high altitude operation of propfan airplanes.

4. PHYSIOLOGICAL LIMITING CRITERIA. The objective of the high altitude standards is to prevent exposing the airplane occupants to environmental conditions that would:

a. Prevent the flightcrew from safely flying and safely landing the airplane, or

b. Cause permanent physiological damage to the occupants.

5. VENTILATION.

a. Section 25.831(a) specifies that the ventilation system must be designed to provide a minimum of 0.55 pounds of fresh air per minute per person (10 cubic feet per minute of air at 8,000 feet pressure altitude and at cabin temperature of 75° F.) for normal operations. If the airplane incorporates a recirculation system, the required fresh air may be mixed with filtered, recirculated air. A larger amount of fresh air may be required due to secondary considerations, such as equipment cooling, window or windshield defogging, control of smoke or toxic fumes, or smoke evacuation. Increased fresh air flow may also be needed in some instances to compensate for high ambient temperatures and humidity. The mass flow following probable failures is addressed in paragraph 5.e of this AC.

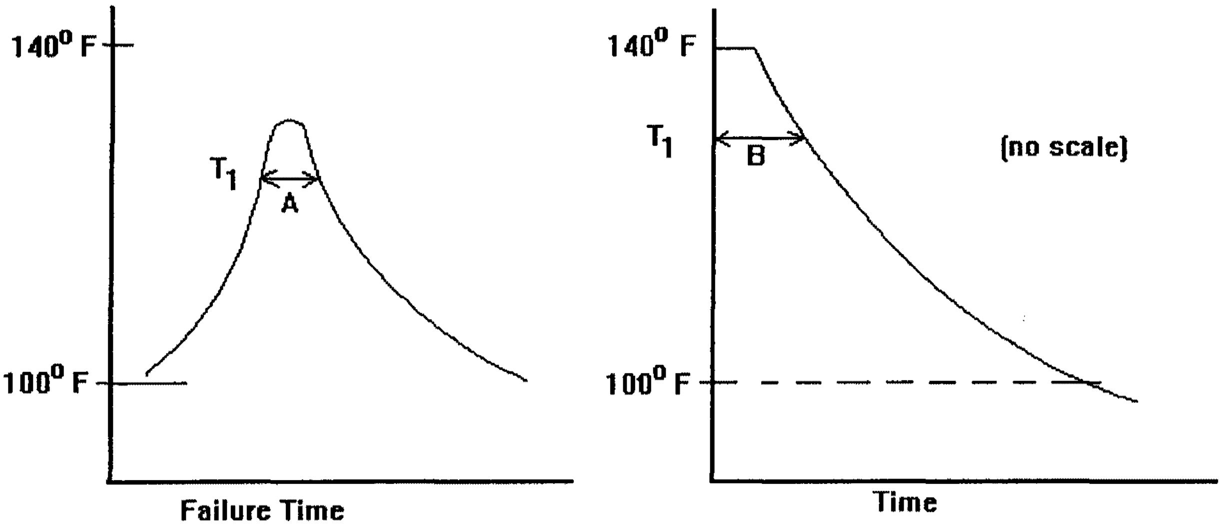
b. Compliance with these requirements may be demonstrated by analysis, ground tests, and/or flight tests. Because it is not practicable to measure the air flow at each occupant's location, the fresh air supplied per minute per occupant may be determined by averaging the total cabin fresh air supply and cockpit fresh air supply for the number of occupants that each area can accommodate.

c. The environmental systems should be investigated for the extremes of the airplane operating envelope. Tests (component, sub-system, airplane) and/or analysis should be used to establish the capabilities of the environmental systems at temperatures anticipated to be encountered in service. For informational purposes, guidelines for climatic extremes may be found in Reference 1, "Military Standard Climatic Extremes for Military Equipment," MIL-STD-210B.

d. Takeoff with the air conditioning or bleed air system "off" may be an acceptable procedure provided the ventilation system continues to provide an acceptable environment in the passenger cabin and cockpit for the brief period when the ventilation system is not operating normally.

e. For probable failure conditions, the ventilation system should be designed to provide enough fresh air to prevent the accumulation of odors and pollutants such as carbon dioxide. Under these conditions, the supply of fresh air should not be less than 0.4 pounds of fresh air per minute per occupant for any period exceeding five minutes. This value also appears in advisory material used by the Joint Aviation Authorities to establish a minimum flow rate following loss of one air source. Temporary reductions below this flow rate may be acceptable provided the compartment environment is maintained at a level which is not hazardous to occupants. This value is based on the minimum airflow for nonsmoking occupied spaces recommended in the ASHRAE 62-1981 standard (the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.). In addition, equipment cooling and ventilation for smoke evacuation should be provided following such failure conditions. The conditions to be considered should include failures of components such as fans, valves, and ducts, failures of a single air conditioning system or bleed air system, and failures of dual air conditioning systems or dual bleed air systems when the systems have common control systems, duct inlet systems, or distribution systems.

f. The purpose of the exposure time-temperature limitation graph of § 25.831(g) is to ensure that emergency pressurization means, such as the use of high temperature air, do not expose airplane occupants to unsafe cabin air temperatures following failures of the normal pressurization system.



The graph of § 25.831(g) is to be used as follows: The left plot above represents the mean cabin temperature (failure temperature) plotted against the time after failure. The right plot is the exposure time-temperature limiting graph of § 25.831(g). Any delays in descent for corrective action or due to operational restrictions should be included in the establishment of the failure temperature curve. The time at any given temperature from the left plot is not to exceed the time at the same temperature of the exposure time-temperature limiting graph. For example, time "A" at temperature T_1 should always be less than or equal to time "B" at the same temperature as checked for each temperature from 100° F. to 140° F.

6. PRESSURIZATION.

a. Sections 25.841(a) and 25.1447(c) are intended to ensure that, following a failure or combination of failures leading to a decompression at the maximum certificated altitude:

(1) The flightcrew will remain alert and able to safely fly and land the airplane;

(2) Occupants of the cabin will be protected from the effects of hypoxia (see Glossary); and

(3) In the event some occupants do not receive supplemental oxygen, they nevertheless will not suffer permanent physiological (brain) damage.

b. Section 25.841(a)(1) is intended to prevent exposing the airplane occupants to extreme environmental conditions resulting from probable failures; however, emergency descent procedures are allowed to be used to meet this requirement. Compliance should be demonstrated by airplane flight tests for the probable failure condition having the most severe effect, starting at the maximum airplane altitude and, when necessary, using emergency descent procedures.

c. Typical probable pressurization failures, similar to ventilation failures, are failures of a single air conditioning system bleed air system, failures of dual air conditioning systems or dual bleed air systems when the systems have common control systems, or other similar single failures. Other probable failure conditions that should be considered involve failures in the outflow valve control or the outflow valve itself.

d. Section 25.841(a)(2)(i) was based on the concept of "Time of Safe Unconsciousness" documented by James G. Gaume (see Reference 2). It is recognized that the use of passenger continuous flow oxygen masks following rapid decompression to cabin altitudes above 34,000 feet may fail to provide protection from hypoxia (see Glossary). It is also recognized that some passengers could be exposed to decompression without oxygen. A few may lose consciousness at 35,000 feet; and others, even with the use of continuous flow oxygen equipment, may lose consciousness at greater altitudes. Exposure to cabin altitudes in excess of 25,000 feet for more than 2 minutes without supplemental oxygen could in some cases cause permanent physiological (brain) damage. Compliance should be demonstrated by calculating the cabin decompression profile using the critical hole size(s) and location, emergency procedures, and a demonstrated emergency descent profile. See the example in Paragraph 10, Emergency Descent.

e. Section 25.841(a)(2)(ii) specifies that occupants must not be exposed to a cabin altitude greater than 40,000 feet after decompression. Oxygen systems cannot protect against all of the effects of decompression, which become more critical at higher altitudes (see Reference 3).

Compliance is demonstrated by calculating the cabin decompression profile using the critical hole size(s) and location, emergency procedures, and a demonstrated emergency descent profile. See the example in Paragraph 10, Emergency Descent.

7. FAILURE CONDITIONS. Section 25.841(a)(3) describes the conditions and failures that should be considered in evaluating cabin decompression. Possible modes of failure, including malfunctions and damage from external sources such as tire burst, wheel failure, engine rotor burst,

engine fan failure, uncontained engine blade failure, loss of antennas, etc., are to be considered. Sections 25.1309 and 25.571, together with their associated AC's, provide guidance in determining definitions of reliability and additional sources of failure. AC 20-128A provides guidance for addressing the hazards associated with uncontained turbine engine and APU rotor failure. Consideration should be given to system failures (both latent and active failures), combinations of system failures, system failure combined with leaks in the pressure vessel (normal and failed seals), failures causing engine shutdown, engine failures causing structural and system damage, structural failures, etc. Typical systems to be considered are engine bleed air systems, air conditioning systems, power sources, outflow valves and their associated control systems, etc. Failures or a combination of failures which expose the occupants to: (1) cabin altitudes in excess of either 25,000 feet for more than 2 minutes, or (2) cabin altitudes that exceed 40,000 feet for any duration, shall be shown to be extremely improbable (see Glossary).

8. FUSELAGE STRUCTURE.

a. Higher operational altitudes could make the loss of cabin pressure due to fuselage skin cracks catastrophic even though the structure remains capable of supporting flight loads. Therefore, pressure-loaded structures for high altitude operation should be designed to be more reliable than those of present airplanes. Additional damage-tolerance requirements are necessary to prevent fatigue and corrosion damage which could result in a rapid depressurization.

b. The cabin altitude/time history should not exceed the limitations of § 25.841(a) after the maximum pressure vessel opening resulting from an initially detectable crack propagating for a period encompassing four normal inspection intervals. Cracks through skin-stringer and skin-frame combinations should be considered. A higher level of structural integrity in the pressure vessel is necessary for high altitude operations.

c. Pressure vessel openings resulting from discrete source damage (§ 25.571(e)) such as a tire burst, wheel failure, engine rotor burst, loss of antenna, etc., or any equipment failure which could result in damage to the pressure vessel, should be analyzed to determine effects on pressurization while operating at maximum cabin differential pressure.

d. The total loss of a window or windshield should be assumed unless it can be shown that total loss is extremely improbable, due to either fatigue failure or to its location with respect to likely sources of damage. Section 25.775 requires that windshields and windows be fail-safe; therefore, total loss of a window due to fatigue failure may be considered extremely improbable if the window is designed fail-safe and capable of withstanding full cabin pressure in conjunction with external aerodynamic pressure with a factor of safety of:

(1) 1.5 for the primary panel alone and 1.15 for the fail-safe panel alone for airplanes approved for pressure altitudes up to 45,000 feet; or

(2) 1.5 for both the primary and fail-safe panels alone for airplanes approved for pressure altitudes above 45,000 feet.

e. Consideration should be given to pressure vessel structural failures (holes or cracks) that may occur in areas of negative pressure differential, because this condition may cause the cabin altitude to exceed the airplane altitude.

f. In calculating the cabin altitude decompression profile, unless a different value can be established by a rational analysis acceptable to the FAA, an orifice discharge coefficient of $C_d = 0.75$ for loss of a window and $C_d = 0.5$ for a hole resulting from fuselage damage should be assumed.

9. ENGINES.

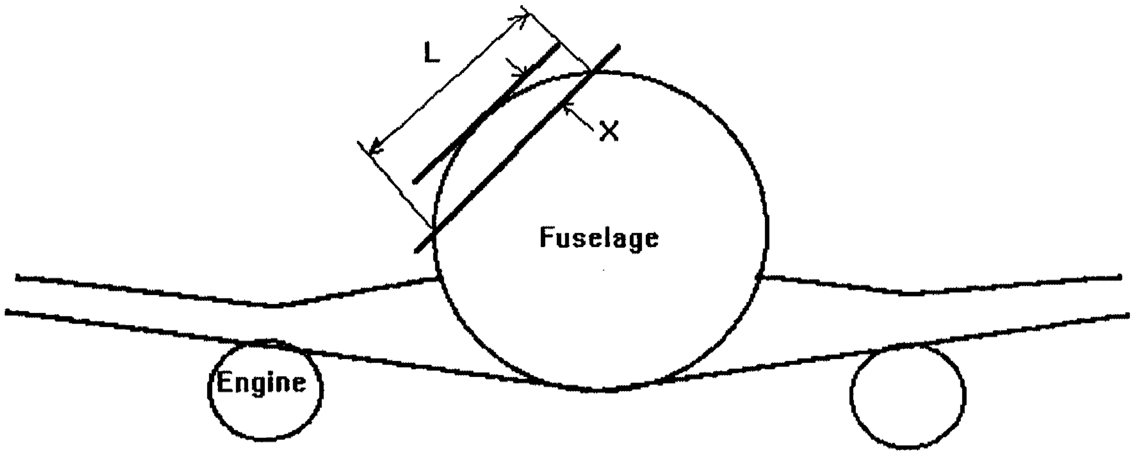
a. Engine rotor burst (including fan, compressor and turbine blades, and rotor disc) and complete loss of thrust from all engines should be considered. Multiple engine failures have occurred due to parallel failure effects, secondary effects, and operational errors. Engine, multiple fan blade, and rotor disc failures have occurred at cruise conditions and have caused decompression. Based on service experience, it must be assumed that these failures will occur.

b. Airplane decompression caused by uncontained engine failure has been experienced; however, decompressions that have occurred have been at flight levels where oxygen equipment provided adequate protection and the service history has been acceptable. Because service history on existing engines is not usually applicable to new engines, the benefits of this service history are limited. Uncontained engine failure is more likely to occur during takeoff and climb; however, approximately 20 percent of these failures occur in cruise, discounting bird strikes. An engine burst at cruise condition must therefore be considered and damage assessment relative to depressurization should be conducted.

c. It has been traditional to base damage assessments and the failure modes and effects on uncontained engine rotor bursts using the classic tri-hub burst (1/3 rotor segment) model. This was, and still is, appropriate considering the energies in rotor failures. However, with the introduction of the high bypass ratio fan engines, fan failures can be the dominant factor in estimating fuselage damage hole sizes. Damage due to uncontained engine fan blades and rotor fragments should be considered to occur in a zone between 15 degrees forward of the fan plane to 15 degrees aft of the last turbine stage plane. Guidance on engine fragment sizes and dispersion angles may be found in AC 20-128A.

d. An inner fuselage tangential strike is assumed. If windows are within a projected strike zone of 15 degrees forward or 15 or more degrees aft of the plane of rotation, use the area of window(s) unless area of the tangential slice due to a rotor fragment determined in accordance with AC 20-128A is greater, in which case the area of the tangential slice should be used.

e. Project a scenario of destruction, an inner fuselage tangential slice.



Typical, but not the only tangential projection possible.
L can be assumed to be the sector distance (i.e., straight line).
X is the engine fragment dimension obtained from AC 20-128A.

f. Propeller fans (propfans or unducted fans) may be considered in an amendment to this AC.

10. EMERGENCY DESCENT

a. In demonstrating compliance with § 25.841, it should be assumed that the oxygen equipment is being used above an airplane operational altitude of 41,000 feet and that an emergency descent is made in accordance with an approved emergency procedure. Crew recognition time for decompression and oxygen mask donning time should be applied between the cabin altitude warning and the beginning of action for descent. The probable system failure having the most severe effect should be demonstrated by flight test at the maximum airplane altitude. For improbable failures, the cabin altitude should be established by an analysis which is verified, if necessary, by tests conducted at a lower altitude.

b. A 17-second delay after decompression for crew recognition and oxygen mask donning time should be applied between cabin altitude warning and initiation of action to configure for descent. The 17-second reaction time was originally based on mean values of emergency responses on simulators in terms of air crew responses in a given emergency situation, where there would actually be pressure loss or some other emergency situation. The 17-seconds is a value that represents the 75th percentile of crew reactions. (Information from Physiological Requirements by Dr. E.G. Vail, WADC, United States Air Force (USAF) - Presented at a USAF symposium on high altitude oxygen requirements in May 1956) Reaction times were further studied by Bennett (see Reference 4). Forty-two pilots were exposed to airplane decompression for an overall cabin rate of climb of 30,000 feet per minute to a maximum cabin altitude of 30,000 feet. Eighty-three percent of the pilots donned

the oxygen mask in 15 seconds. Emergency descent was initiated in all cases within 5 seconds of the fitting of the mask.

c. The following example of a pressurization failure should make clear the use of delays and environmental limitations.

Assumption and definitions: H_N = The normal cabin pressure altitude which is less than or equal to 8,000 feet normally.

H_A = Airplane altitude.

Tf = Time of pressurization failure.

T_W = Time of the 10,000 foot cabin pressure altitude warning.

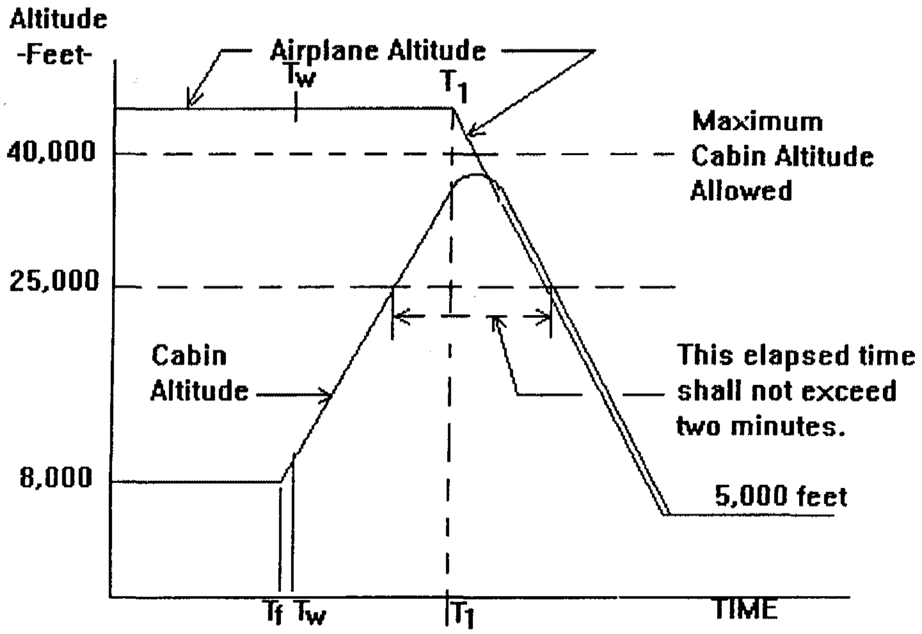
T1 = Time that the airplane descent begins.

T_R = Recognition time for crew response to emergency annunciation (17 seconds).

T_S = Time for trouble-shooting or damage assessment; for example, switching the outflow valve to "manual" to attempt to regain cabin altitude control.

T_D = Time to configure the airplane for descent; for example, gear extension.

$T1-T_W$ = Delay time from cabin altitude warning to time that the airplane begins to descend $= T_R + T_S + T_D$.



d. The time for trouble-shooting and time to achieve descent configuration may be based on analysis and simulation. Once the critical failures have been selected, these delays should be evaluated to verify that the descent rate is one which a typical operating crew can achieve. The descent rate established should be reflected in the flight manual procedures and the flight manual should also recommend descending to 5,000 feet if practical when operation exceeds 35,000 feet. See Reference 2, page 385.

e. The limitations of § 25.841(a)(2) are not intended to be used in calculating the quantity of oxygen that is needed for emergency descent and sustenance. The flightcrew may inadvertently, or by intent, delay descent for any number of reasons. Different descent rates may be established. The operating rules specify the quantity of oxygen that must be carried.

11. OXYGEN EQUIPMENT. Both diluter demand and pressure demand oxygen equipment (see Glossary) have proven to be satisfactory for use up to cabin pressure altitudes of 40,000 feet when the person using the oxygen equipment is exposed to a gradual altitude rate of climb. The oxygen equipment required by Amendment 25-87 will provide protection against the effects of hypoxia for the cabin altitudes allowed under the new requirements.

12. GLOSSARY.

Physiological Altitude Limits. The response of human beings to increased altitude varies with the individual. People that smoke or are in poor health will be affected at a much lower altitude than people who are young and in good physical condition. Without supplementary oxygen, most people will begin to experience a reduction in night vision or general visual acuity at approximately 5,000 feet altitude. At an altitude of approximately 10,000 feet, a person will begin to display measurable deterioration in mental abilities and physical dexterity after a period of several hours. At 18,000 feet, the mental deterioration may result in unconsciousness, and the time of useful consciousness (TUC) is generally about 15 minutes. At 25,000 feet, the TUC for most people is about 3-10 minutes. At altitudes above 25,000 feet, the TUC decreases very rapidly, becoming only a few seconds at 40,000 feet. If a person is breathing 100 percent oxygen, however, the partial pressure of oxygen in the lungs at 34,000 feet altitude is the same as that for a person breathing air at sea level. At 40,000 feet, a person breathing 100 percent oxygen will have the same partial pressure of oxygen in the lungs as a person breathing air at 10,000 feet. Therefore, 34,000 feet is the highest altitude at which a person would be provided complete protection from the effects of hypoxia, and 40,000 feet is the highest altitude at which 100 percent oxygen will provide reasonable protection for the limited period of time needed to descend to a safe altitude.

Hypoxia. Hypoxia is an insufficient supply of oxygen. Hypoxia results from the reduced oxygen partial pressure in the inspired air caused by the decrease in barometric pressure with increasing altitude.

Diluter Demand Oxygen System. A flightcrew oxygen system consisting of a close-fitting mask with a regulator that supplies a flow of oxygen dependent upon cabin altitude. Regulators approved for use up to 40,000 feet are designed to provide zero percent cylinder oxygen and 100 percent cabin air at cabin altitudes of 8,000 feet or less, with the ratio changing to 100 percent oxygen and zero percent cabin air at approximately 34,000 feet cabin altitude. Regulators approved up to 45,000 feet are designed to provide forty percent cylinder oxygen and 60 percent cabin air at lower altitudes, with the ratio changing to 100 percent at the higher altitude. Oxygen is supplied only when the user inhales, reducing the amount of oxygen that is required.

Pressure Demand Oxygen System. Similar to diluter demand equipment, except that oxygen is supplied to the mask under pressure at cabin altitudes above approximately 34,000 feet. This pressurized supply of oxygen provides some additional protection against hypoxia at altitudes up to 40,000 feet.

Pressure Demand Mask with Mask-Mounted Regulator. A pressure demand mask with the regulator attached directly to the mask, rather than mounted on the instrument panel or other area within the flight deck. The mask-mounted regulator eliminates the problem of a long hose which must be purged of air before 100 percent oxygen begins flowing into the mask.

Continuous Flow Oxygen System. The oxygen system usually provided for passengers. The passenger mask typically has a reservoir bag, which collects oxygen from the continuous flow oxygen system during the time when the mask user is exhaling. The oxygen collected in the reservoir bag allows a higher inspiratory flow rate during the inhalation cycle, which reduces the amount of air dilution. Ambient air is added to the supplied oxygen during inhalation after the reservoir bag oxygen supply is depleted. The exhaled air is released to the cabin.

Probable Failures. Probable failures may be expected to occur several times during the operational life of each airplane. The probability of occurrence is on the order of 1×10^{-5} or greater (see Advisory Circular 25.1309-1A). The consequences of the failure or the required corrective action may not
significantly impact the safety of the airplane or the ability of the crew to cope with adverse operating conditions.

Improbable Failures. Improbable failures are not expected to occur during the total operational life of a random single airplane of a particular type, but may occur during the total operational life of all airplanes of a particular type. The probability of occurrence is on the order of 1×10^{-5} or less, but greater than 1×10^{-9}. The consequences of the failure or the required corrective action must not prevent the continued safe flight and landing of the airplane.

Extremely Improbable Failures. Extremely improbable failures are so unlikely that they need not be considered to ever occur, unless engineering judgment would require their consideration. The probability of occurrence is on the order of 1×10^{-9} or less. This category includes failures or combinations of failures that would prevent the continued safe flight and landing of the airplane.

13. REFERENCES.

a. Reference 1. "Military Standard Climatic Extremes for Military Equipment, MIL-STD-210B."

b. Reference 2. "Factors Influencing the Time of Safe Unconsciousness (TSU) for Commercial Jet Passengers Following Cabin Decompression" by James G. Gaume, Aerospace Medicine, April 1970.

c. Reference 3. Aerospace Information Report (AIR) No. 822 and 825A (Physiology Section); SAE Committee A-10.

d. Reference 4. "Reactions and Performance of Pilots Following Decompression by G. Bennett, Aerospace Medicine, February 1964.

14. FOR FURTHER READING.

a. AC 20-32B, Carbon Monoxide (CO) Contamination in Aircraft - Detection and Prevention.

b. AC 91-8B, Use of Oxygen by Aviation Pilots/Passengers.

d. Bioastronautics Data Book, NASA SP-3006, National Aeronautics and Space Administration.

e. An Analysis of the Oxygen Protection Problem at Flight Altitudes Between 40,000 and 50,000 Feet, Final Report, Contract FA-955, by W. V. Blockley and D. T. Hanifan.

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